Terrestrial Planet Finder Mission

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Orbits Design for Exoplanet Missions

Trajectory & Mission Design

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Agenda

- Background
- Trajectory Options
- Assumptions
- Impulsive Case
- Low Thrust Case
- Conclusions
- Future Work
- References

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Background

- **TPF Occulter for Planet Finding**
  - **TRW Study: Starkman's Concept, Precursor Mission with JWST**
  - **Identified 2 Tall Tent Poles: *Orbital Dynamics*, Occulter Fabrication**
- **JPL Study Finds Orbital Dynamics Not a Problem**
- **JPL Mission Design and Navigation Expertise**
  - **Cutting Edge Mission Design & Navigation Technologies**
  - **Analysis and Design of All Type of Mission Scenarios and Orbits**
  - **Experience**
  - **End-to-End Service: Pre-Phase-A to Operations**

Assumptions for Study

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- **Two Free Flying Spacecraft: Telescope & Occulter**
- **Separation 10,000 to 50,000 km**
- **Observation Duration 24 Hours / Star**
- **Orbits in Sun-Earth/Moon Restricted Three Body Problem**
  - **μ=3.04042e-06**
  - **~JWST L_2 Lissajous Orbit (187,000 x 750,000 km Az, Ay Amplitudes)**
  - **Earth Leading Orbit**
  - **Model Adequate to Size Propulsion & Show Feasibility**
- **Monte Carlo Analysis Observing Random Stars**
- **Simulations for Observing 40 Stars from TPF List**

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Observation Geometry Assumptions

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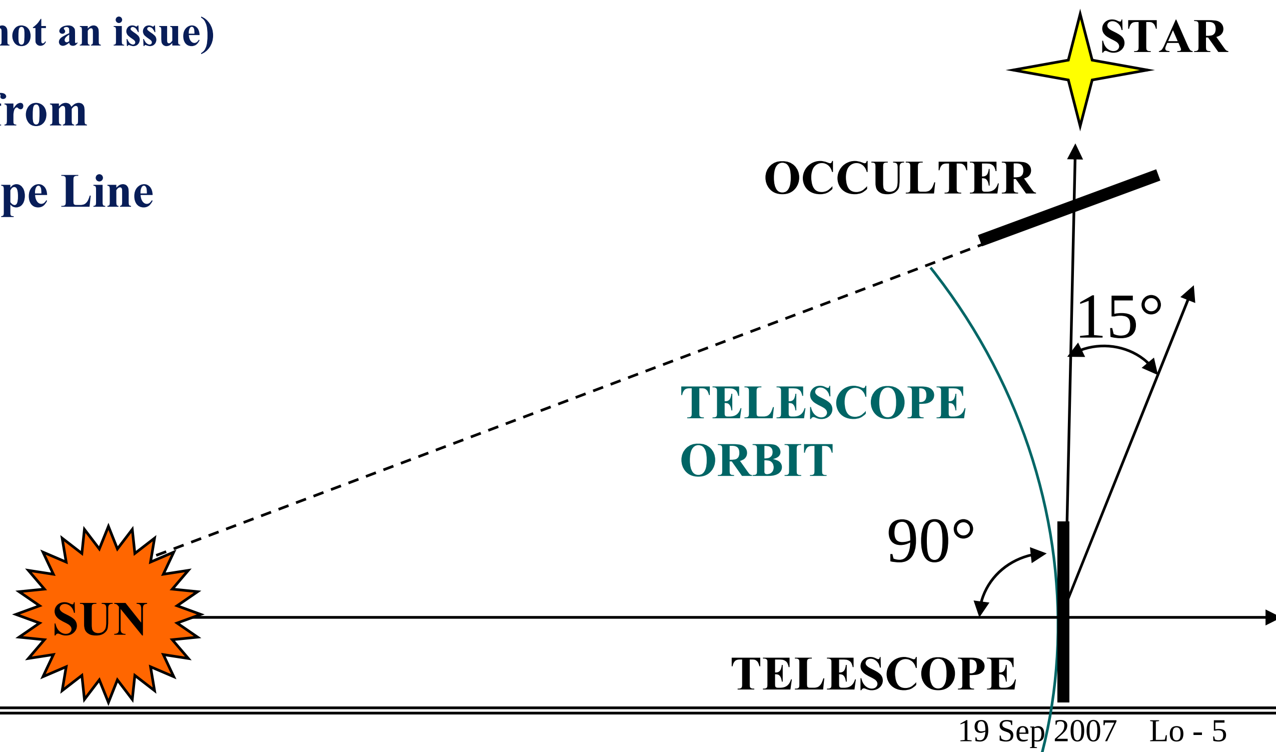
- **Telescope Always Sun-Pointed**
  - **Using JWST as Model (Gardner et al. 2006)**
  - **SKM (Station Keeping Maneuver) Every 22 Days**
  - **Area: 19.4 x 16.4 [m^2]**
- **Occulter Always 90° to Sun-Occulter-Line**
  - **Area: 25 m Radius Circle (W. Case 2006)**
  - **Assume No SRP (not an issue)**
- **Telescope FOV 15° from Plane ⊥ Sun-Telescope Line**
- **Retargeting Angle:**

  ≤ 15° Case 1

  = 15° Case 2

  ≤ 30° Case 3



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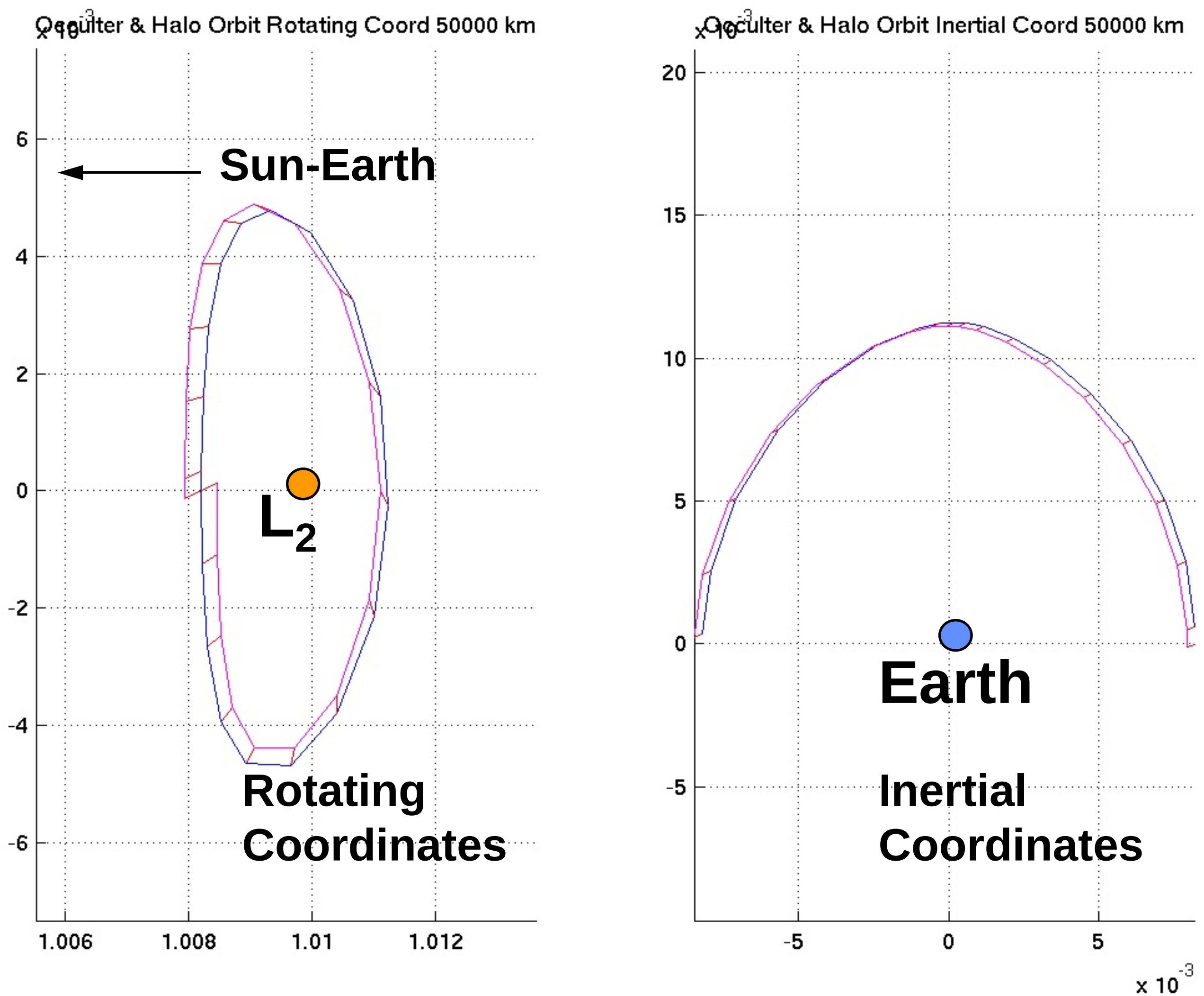
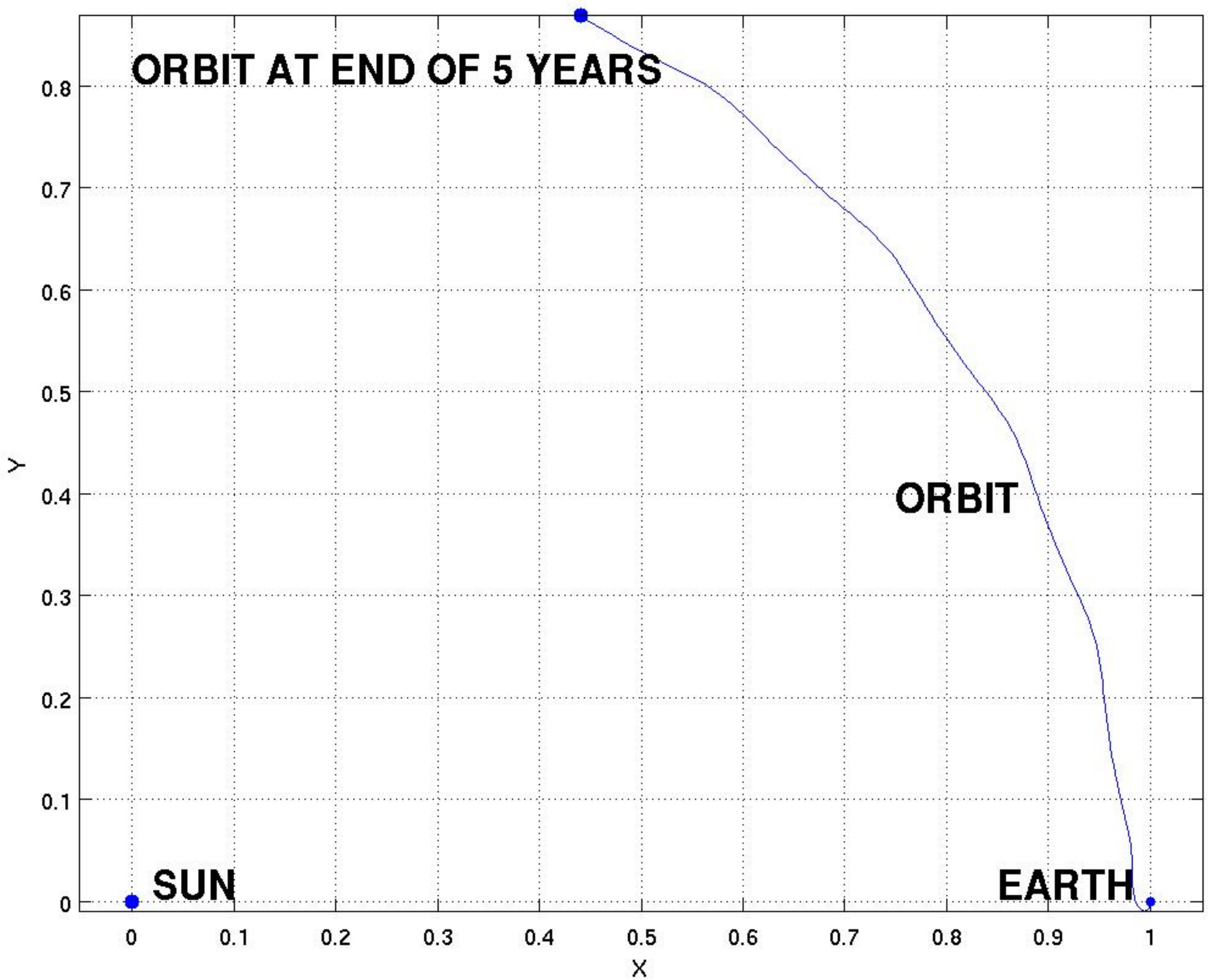
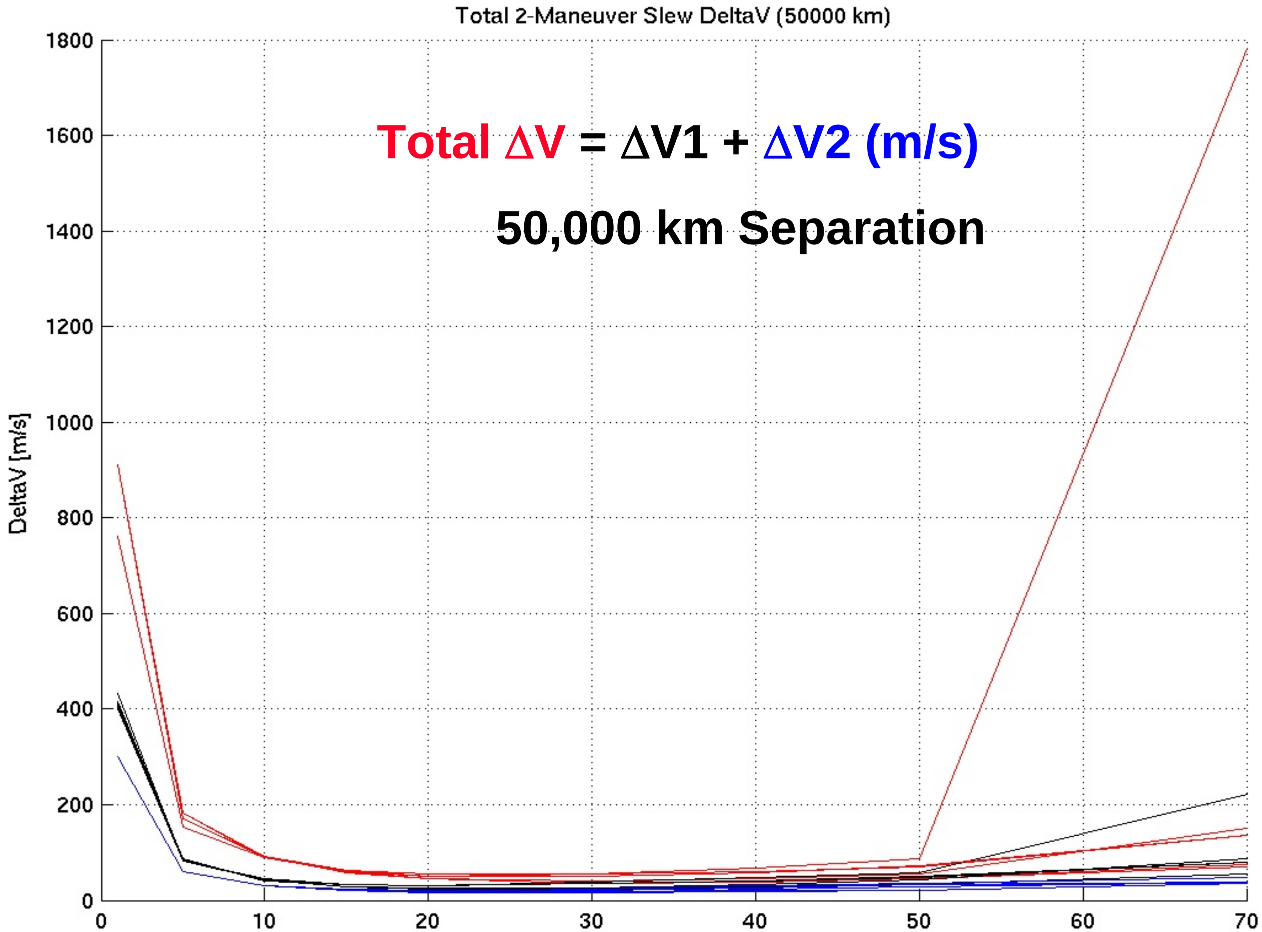
L_2 Orbits for Occulter & Telescope



Earth Leading Heliocentric Orbit



Mean Retargeting ΔV in Halo Orbit



SLEW DURATION (DAYS)

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ΔV Distribution for 1 Day Observation in Halo Orbit

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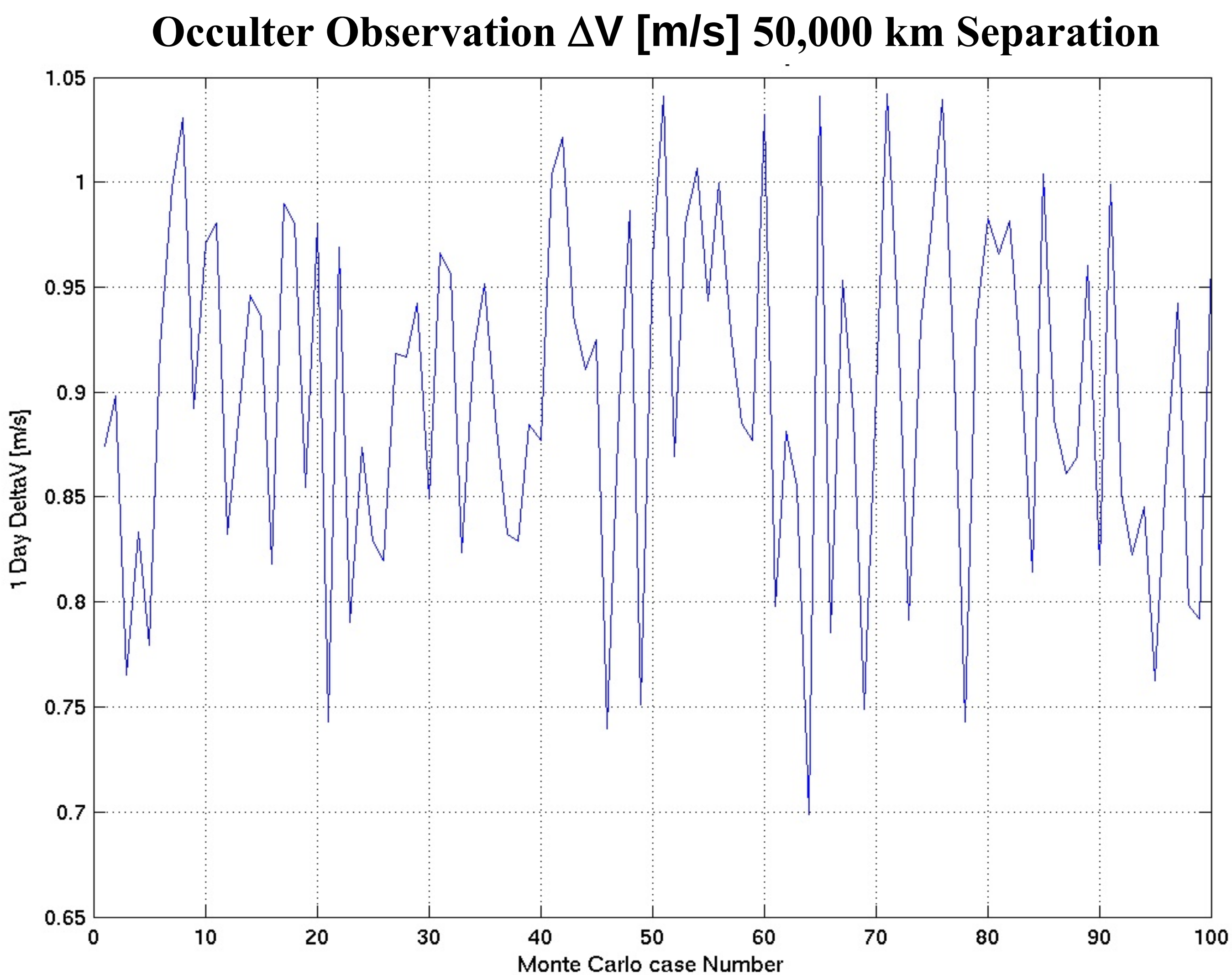

Halo Orbits Chemical ΔV More Expensive

- **Observation ΔV 6 x More Expensive in L_2 Halo Orbit Than Heliocentric Orbit**
- **Repointing ΔV 2.6 x More Expensive in Halo Orbit**
- ***BUT* Halo Orbit Mission Much Faster**
  - **Optimum Transfer Time: 30 to 40 Days in Heliocentric Orbit**
  - **10 to 15 Days in Halo Orbit**

Observation ΔV (1 Day)	50,000 km Separation	25,000 km Separation
L_2 Orbit	1.2 m/s	0.6 m/s
Helio. Orbit	0.2 m/s	0.1 m/s
Repointing ΔV		
L_2 Orbit	19 m/s	9.5 m/s
Helio. Orbit	7.1 m/s	3.6 m/s

Performance in Earth Leading Orbit

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- Chem. Thrust: Chem Wet/Dry ~ 0.9159 ± .00013
- Low Thrust: 1600 kg propulsion for 3000 kg dry S/C (Yen)
  - 10 Days Repointing, 440 Days for Observing 40 Stars
- Spacecraft Mass [kg]:

DRY (KG)	CHEM PROP	CHEM WET	SEP PROP	SEP WET	SEP - CHEM
1000	1092	2092	533	1533	-559
2000	2184	4184	1067	3067	-1117
3000	3275	6275	1600	4600	-1675
4000	4367	8367	2133	6133	-2234
5000	5459	10459	2667	7667	-2792

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Conclusions

- **TPFO with SEP Feasible in L_2 Halo Orbits**
- **Occulter Must Be Controlled During Observation**
  - **Uncontrolled Drift in 1 Day**
    - ~ 0.1 km in heliocentric orbit
    - ~10 km in halo orbit
- **TPFO with Impulsive ΔV Difficult to Achieve**
  - **ΔV Feasible for Heliocentric Orbits, Not for *LARGE* L_2 Halo Orbits**
  - **Duration Too Long for Heliocentric Orbits, OK for Halo Orbits**
- **Occulter with JWST**
  - **Suitable For Finding Jupiter Planets (≤ 25,000 km separation)**
  - **Not Suitable For Finding *TERRESTRIAL* Planets Due to Large ΔV Requirements (≥ 50,000 km separation)**
- **TPFO Not Feasible with Solar Sails**

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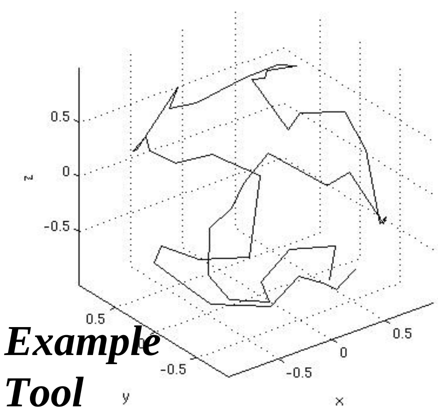
On Going Work

- **Performance Trade in Halo Orbit Still Remains**
  - **Need Low Thrust Mass Analysis**
- **Station Keeping Analysis Needed**
- **Travelling Planet Finder Problem**
  - **Optimize Observation & Propulsion with Constraints**
  - **Hard Multiobjective Optimization Problem**
  - **Stochastic Optimization Approach Need**
    - e.g. Genetic Algorithm, Markov Chain Mor
  - **Building Tools**



Traveling Salesman Example Using CONCORDE Tool

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Trajectory Study Team

- **Martin Lo**
- **Chen-Wan Yen**
- **Ryan Russell**
- **Stefano Campangola (USC, Graduate Student)**

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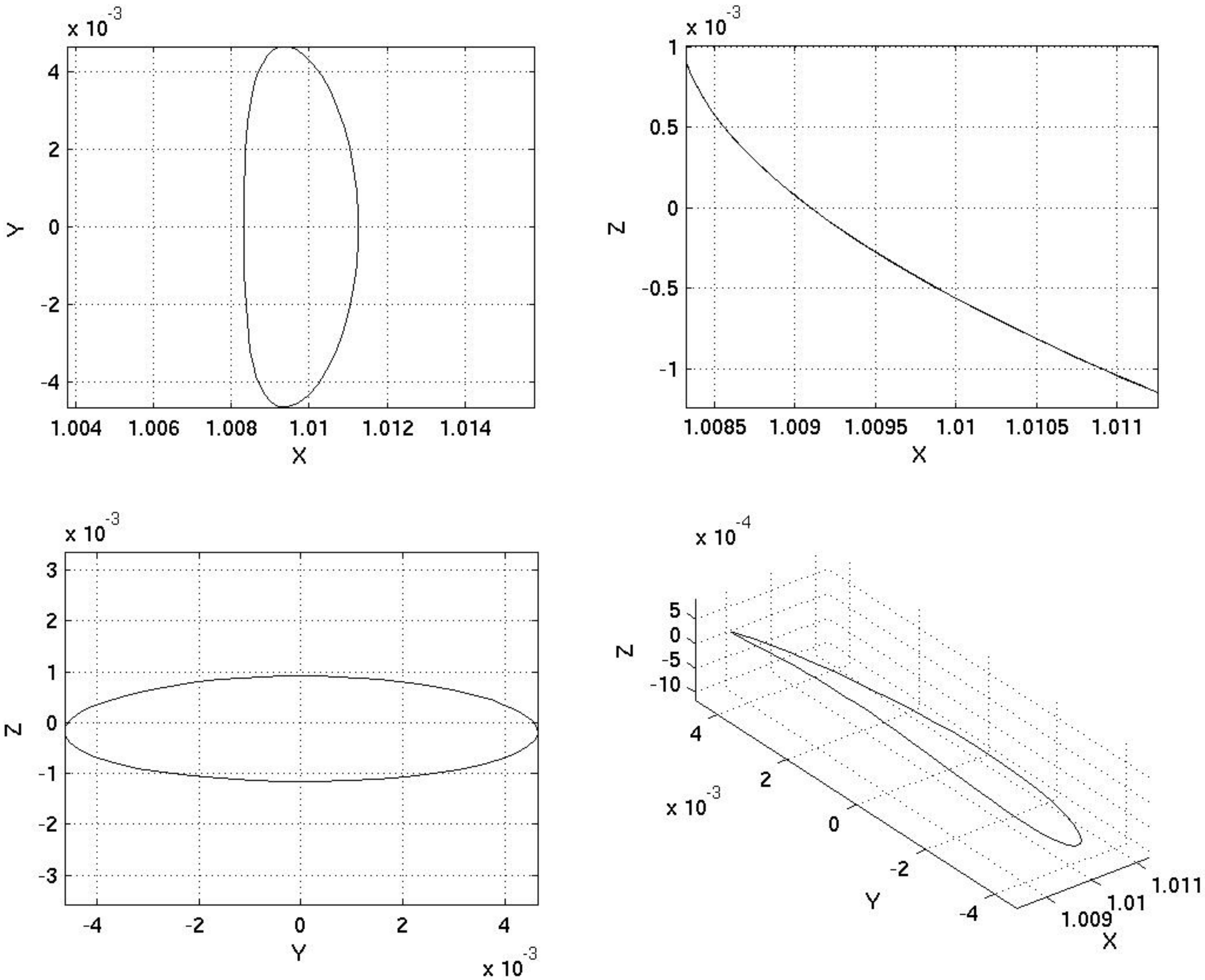
L_2 Halo Orbit (Rotating Coord)



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